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MEMORANDUM**

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REPORT FOR NATIONAL TRANSONIC FACILITY FOR
9% NICKEL TUNNEL SHELL. VOLUME 6: FATIGUE
ANALYSIS (NASA) 46 p HC \$4.00 CSCI 13M

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**LaRC DESIGN ANALYSIS REPORT
FOR
NATIONAL TRANSONIC FACILITY
FOR
9% NICKEL TUNNEL SHELL
FATIGUE ANALYSIS**

VOL. 6

BY

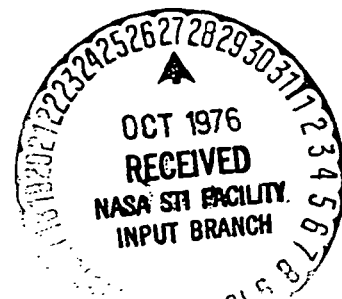
**JAMES W. RAMSEY, JR., JOHN T. TAYLOR, JOHN F. WILSON,
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National Aeronautics and
Space Administration

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| 16. Abstract This report contains the results of extensive computer (finite element, finite difference and numerical integration), thermal, fatigue, and special analyses of critical portions of a large pressurized, cryogenic wind tunnel (National Transonic Facility). The computer models, loading and boundary conditions are described. Graphic capability was used to display model geometry, section properties, and stress results. A stress criteria is presented for evaluation of the results of the analyses. Thermal analyses were performed for major critical and typical areas. Fatigue analyses of the entire tunnel circuit is presented. The major computer codes utilized are: SPAR - developed by Engineering Information Systems, Inc. under NASA Contracts NAS8-30536 and NAS1-13977; SALORS - developed by Langley Research Center and described in NASA TN D-7179; and SRA - developed by Structures Research Associates under NASA Contract NAS1-10091; "A General Transient Heat-Transfer Computer Program for Thermally Thick Walls" developed by Langley Research Center and described in NASA TM X-2058. | | | | | |
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NTF TUNNEL SHELL
NASA LARC

FATIGUE ANALYSIS

9% Ni

SEPTEMBER 1976

VOLUME 6

LaRC CALCULATIONS
FOR THE
NATIONAL TRANSONIC FACILITY
TUNNEL SHELL

DATE: SEPTEMBER, 1976

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This report is one volume of a Design Analysis Report prepared by LaRC on portions of the pressure shell for the National Transonic Facility. This report is to be used in conjunction with reports prepared under NASA Contract NAS1-13535(c) by the Ralph M. Parsons Company (Job Number 5409-3 dated September 1976) and Fluidyne Engineering Corporation (Job Number 1060 dated September 1976). The volumes prepared by LaRC are listed below:

1. Finite Difference Analysis of Cone/Cylinder (9% Ni), Vol. 1, NASA TM X73956-1.
2. Finite Element Analysis of Corners #3 and #4 (9% Ni), Vol. 2, NASA TM X73956-2.
3. Finite Element Analysis of Plenum Region Including Side Access Reinforcement, Side Access Door and Angle of Attack Penetration (9% Ni), Vol. 3, NASA TM X73956-3.
4. Thermal Analysis (9% Ni), Vol. 4, NASA TM X73956-4.
5. Finite Element and Numerical Integration Analyses of the Bulkhead Region (9% Ni), Vol. 5, NASA TM X73956-5.
6. Fatigue Analysis (9% Ni), Vol. 6, NASA TM X73956-6.
7. Special Studies (9% Ni), Vol. 7, NASA TM X73956-7.

NTF DESIGN CRITERIA
FOR 9% NICKEL

GENERAL

THE DESIGN OF THE PRESSURE SHELL REFLECTED IN THIS REPORT SATISFIES THE DESIGN REQUIREMENTS OF THE ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 1. SINCE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN, ADDITIONAL ANALYSES WERE PERFORMED IN AREAS HAVING COMPLEX CONFIGURATIONS SUCH AS THE CONE CYLINDER JUNCTIONS, THE GATE VALVE BULKHEADS, THE BULKHEAD-SHELL ATTACHMENTS, THE PLENUM ACCESS DOORS AND REINFORCEMENT AREAS, THE ELLIPTICAL CORNER SECTIONS, AND THE FIXED REGION (RING S8) OF THE TUNNEL. THE DIVISION 1 DESIGN CALCULATIONS, THE ADDITIONAL ANALYSES AND THE CRITERIA FOR EVALUATION OF THE RESULTS OF THE ADDITIONAL ANALYSES TO ENSURE COMPLIANCE WITH THE INTENT OF DIVISION 1 REQUIREMENTS ARE CONTAINED IN THE TEXT OF THIS REPORT. THE DESIGN ANALYSES AND ASSOCIATED CRITERIA CONSIDERED BOTH THE OPERATING AND HYDROSTATIC TEST CONDITIONS.

IN CONJUNCTION WITH THE DESIGN, A DETAILED FATIGUE ANALYSIS OF THE PRESSURE SHELL WAS ALSO PERFORMED UTILIZING THE METHODS OF THE ASME CODE, SECTION VIII, DIVISION 2.

MATERIAL

THE PRESSURE SHELL MATERIAL SHALL BE ASME, SA-553-1 FOR PLATE AND SA-522 FOR FORGINGS. THE MATERIAL PROPERTIES AT TEMPERATURES EQUAL TO OR BELOW 150°F ARE AS FOLLOWS:

(A) PLATE, 2.0 INCHES OR THINNER

YIELD = 85.0 KSI
ULTIMATE = 100 KSI

(B) WELDS (AUTOMATIC AND SEMIAUTOMATIC)

YIELD = 52.5 KSI
ULTIMATE = 95.0 KSI

(C) WELDS (HAND)

YIELD = 58.5 KSI
ULTIMATE = 95.0 KSI

OPERATING, DESIGN AND TEST CONDITIONS

THE OPERATING, DESIGN AND TEST CONDITIONS FOR THE TUNNEL PRESSURE SHELL AND ASSOCIATED SYSTEMS AND ELEMENTS ARE SUMMARIZED BELOW:

1. OPERATING MEDIUM

ANY MIXTURE OF AIR AND NITROGEN

2. DESIGN TEMPERATURE RANGE

MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT, EXCEPT IN THE REGION OF THE PLENUM BULKHEADS AND GATE VALVES INSIDE A 23-FOOT, 4-INCH DIAMETER, FOR WHICH THE TEMPERATURE RANGE IS MINUS 320 DEGREES FAHRENHEIT TO PLUS 200 DEGREES FAHRENHEIT.

3. PRESSURE RANGE

| TUNNEL CONFIGURATION | OPERATING PRESSURE RANGE, PSIA | DESIGN PRESSURES PSID |
|---|--------------------------------------|-----------------------------------|
| A. CONDITION I - PLENUM ISOLATION GATES OPEN AND TUNNEL OPERATING: | | |
| TUNNEL CIRCUIT EXCEPT PLENUM | 8.3 to 130 | A. 8 EXTERNAL B. 119 INTERNAL |
| PLENUM (PLENUM PRESS- URE IS LIMITED TO .4 TO 1 TIMES THE REMAINDER OF THE TUNNEL CIRCUIT | 3.3 to 130 | A. 15 EXTERNAL B. 119 INTERNAL |
| BULKHEAD | | 56 (EXTERNAL TO PLENUM) |
| B. CONDITION II - PLENUM ISOLATION GATES OPEN AND TUNNEL SHUTDOWN: | | |
| ENTIRE TUNNEL CIRCUIT | 8.3 to 130 | A. 8 EXTERNAL B. 119 INTERNAL |
| BULKHEAD | | 0 |

C. CONDITION III - PLENUM
ISOLATION GATES AND
ACCESS DOORS CLOSED:

| | | |
|---------------------------------|------------|----------------------------------|
| TUNNEL CIRCUIT EXCEPT PLENUM | 8.3 to 130 | A. 8 EXTERNAL B. 119 INTERNAL |
|---------------------------------|------------|----------------------------------|

| | | |
|--|----------|-----------------------------------|
| PLENUM (PLENUM OPER- ATING PRESSURE CAN EXCEED THE PRESSURE IN THE REMAINDER OF THE TUNNEL CIRCUIT BY 24 PSI, BUT DOES NOT EXCEED THE 130 PSIA MAXIMUM OPERATING PRESSURE) | 0 to 130 | A. 15 EXTERNAL B. 119 INTERNAL |
|--|----------|-----------------------------------|

| | | |
|----------|--|---|
| BULKHEAD | | A. 25 (INTERNAL TO PLENUM) B. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT |
|----------|--|---|

*C. 110.5 (EXTERNAL TO
PLENUM) FOR PLUS
151 DEGREES
FAHRENHEIT TO PLUS
200 DEGREES
FAHRENHEIT

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

D. CONDITION IV - PLENUM
ISOLATION GATES CLOSED
AND ACCESS DOORS OPEN:

| | | |
|---------------------------------|------------|----------------------------------|
| TUNNEL CIRCUIT EXCEPT PLENUM | 8.3 to 130 | A. 8 EXTERNAL B. 119 INTERNAL |
|---------------------------------|------------|----------------------------------|

| | | |
|--------|------|---|
| PLENUM | 14.7 | 0 |
|--------|------|---|

| | | |
|----------|--|---|
| BULKHEAD | | A. 119 (EXTERNAL TO PLENUM) FOR MINUS 320 DEGREES FAHRENHEIT TO PLUS 150 DEGREES FAHRENHEIT |
|----------|--|---|

*B. 110.5 (EXTERNAL TO
PLENUM) FOR PLUS 151
DEGREES FAHRENHEIT TO PLUS
200 DEGREES FAHRENHEIT

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

*OPERATING PROCEDURES LIMIT PRESSURES TO THAT SHOWN.

4. HYDROSTATIC TEST DESIGN CONDITIONS

THE PRESSURE SHELL WAS DESIGNED FOR HYDROSTATIC TEST IN ACCORDANCE WITH THE REQUIREMENTS OF THE ASME CODE, SECTION VIII, DIVISION 1. THE TEST PRESSURES SHALL BE AS FOLLOWS. PRESSURE SHELL TEMPERATURE SHALL BE EQUAL TO OR BELOW 100°F DURING HYDROSTATIC TESTS.

CONDITION (1) - MAXIMUM INTERNAL PRESSURE CONDITION FOR THE ENTIRE TUNNEL CIRCUIT

$$\begin{aligned} PH_1 &= 1.5 (119) + \text{HYDROSTATIC HEAD} \\ &= 178.5 \text{ PSI} + \text{HYDROSTATIC HEAD} \end{aligned}$$

CONDITION (2) - MAXIMUM DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$\begin{aligned} PH_2 &= 1.5 (119) + \text{HYDROSTATIC HEAD} \\ &= 178.5 + \text{HYDROSTATIC HEAD} \end{aligned}$$

$$\begin{aligned} PH_2^* &= 1.5 (111.5) \left(\frac{23.7}{22.2} \right) + \text{HYDROSTATIC HEAD} \\ &= 178.5 + \text{HYDROSTATIC HEAD} \end{aligned}$$

*TUNNEL OPERATION LIMITATIONS PRECLUDE PRESSURE DIFFERENTIALS ACROSS BULKHEADS IN EXCESS OF 110.5 PSI FOR BULKHEAD AND GATE TEMPERATURES IN EXCESS OF 150°F.

CONDITION (3) - MAXIMUM REVERSE DIFFERENTIAL PRESSURE CONDITION ACROSS THE PLENUM BULKHEADS

$$PH_3 = 1.5 (25) = 37.5 \text{ PSI}$$

THE PRESSURE SHELL EXCEPT FOR THE PLENUM SHALL BE PRESSURIZED TO 141 PSIG. THE PLENUM SHALL BE PRESSURIZED TO 178.5 PSIG.

PRESSURE SHELL STRESS EVALUATION CRITERIA

THIS CRITERIA ESTABLISHES THE BASIS FOR ANALYSIS AND DESIGN OF THE PRESSURE SHELL SO IT WILL MEET OR EXCEED ALL OF THE REQUIREMENTS OF SECTION VIII, DIVISION 1 OF THE ASME BOILER AND PRESSURE VESSEL CODE AND CAN BE STAMPED WITH A DIVISION 1 "U" STAMP.

1. SECTION VIII, DIVISION 1, DIRECT APPLICATION

A. THE MAXIMUM ALLOWABLE STRESS (S)

$$S = 23.7 \text{ KSI } (-320^{\circ}\text{F TO } +150^{\circ}\text{F})$$

$$S = 22.2 \text{ KSI } (-320^{\circ}\text{F TO } +200^{\circ}\text{F})$$

(B) PRIMARY BENDING PLUS PRIMARY MEMBRANE STRESSES

THE LOCAL MEMBRANE STRESSES ARE NOT GENERALLY CONSIDERED IN SECTION VIII, DIVISION 1 DESIGNS. HOWEVER, FOR THE PURPOSE OF DESIGNING LOCAL REINFORCEMENT AT BRACKETS, RINGS OR PENETRATIONS NOT COVERED BY DESIGN BASED ON STRESS ANALYSIS, THE LOCAL SHELL MEMBRANE STRESS SHALL BE:

$$P_b + P_m \leq 1.5 SE$$

NOTE: E IS JOINT EFFICIENCY

2. IN REGIONS OF THE PRESSURE SHELL WHERE DIVISION 1 DOES NOT CONTAIN RULES TO COVER ALL DETAILS OF DESIGN (REF. U-2(g)), ADDITIONAL ANALYSES WERE PERFORMED UTILIZING THE GUIDELINES OF THE ASME CODE, SECTION VIII, DIVISION 2, APPENDIX 4, "DESIGN BASED ON STRESS ANALYSIS." THE BASIC STRESS CRITERIA FOR DIVISION 2 IS REPRESENTED IN FIGURE 4-130.1 AND RESTATED BELOW INDICATING ANY MODIFICATIONS OR EXCESS REQUIREMENTS APPLIED TO IT TO REMAIN WITHIN THE INTENT OF DIVISION 1 AND TO OBTAIN A DIVISION 1 STAMP.

A. GENERAL PRINCIPAL MEMBRANE STRESS

MAXIMUM ALLOWABLE STRESS

$$S = 23.7 \text{ KSI } (-320^{\circ}\text{F TO } +150^{\circ}\text{F})$$

$$S = 22.2 \text{ KSI } (-320^{\circ}\text{F TO } +200^{\circ}\text{F})$$

MAXIMUM ALLOWABLE STRESS INTENSITY

$$S_m = 31.7 \text{ KSI } (-320^{\circ}\text{F TO } +200^{\circ}\text{F})$$

B. PRIMARY GENERAL MEMBRANE STRESS INTENSITY

$$P_m \leq S_m$$

AND IN ORDER TO COMPLY WITH DIVISION 1, THE MAXIMUM PRINCIPAL MEMBRANE STRESS MUST BE:

$$P_m^* \leq S$$

NOTE: THE * IS USED TO DENOTE THAT MAXIMUM PRINCIPAL STRESSES ARE TO BE COMPUTED FOR THE GIVEN LOADING CONDITION. THE INTENT IS TO DETERMINE THE STRESSES WHICH REPRESENT THE HOOP STRESSES AND MERIDIONAL STRESSES WHICH ARE THE STRESSES USED IN DIVISION 1 COMPUTATIONS.

C. DESIGN LOADS, PRIMARY LOCAL MEMBRANE STRESS INTENSITY

$$P_L \leq 1.5 S_m$$

NOTE: LOCAL MEMBRANE STRESS INTENSITY IS DEFINED IN ACCORDANCE WITH DIVISION 2, APPENDIX 4-112(i). THE TOTAL MERIDIONAL LENGTH IS CONSIDERED TO BE $1.0 \sqrt{RT}$.

D. DESIGN LOADS, PRIMARY LOCAL MEMBRANE PLUS PRIMARY BENDING STRESS INTENSITY

$$P_L + P_b \leq 1.5 S_m$$

E. OPERATING LOADS, PRIMARY PLUS SECONDARY STRESS INTENSITY

$$P_L + P_b + Q \leq 3 S_m$$

F. COMMENT

BECAUSE OF THE LOW YIELD STRENGTH EXPECTED AT THE WELDS AS COMPARED TO THE YIELD STRENGTH OF THE PLATE, STRESS INTENSITIES COMPUTED IN (A), (B), (C), (D), OR (E) SHALL NOT EXCEED THE YIELD STRENGTH OF THE MATERIAL AT EITHER WELD OR PLATE LOCATIONS.

3. A FATIGUE ANALYSIS WAS CONDUCTED IN ACCORDANCE WITH SECTION VIII, DIVISION 2 WITHOUT MODIFICATION.

4. HYDROSTATIC TEST CONDITION DESIGN CONSIDERATIONS

A. PRESSURE SHELL

IN ACCORDANCE WITH DIVISION 1 OF THE ASME CODE, DESIGN ANALYSIS OF THE PRESSURE SHELL FOR THE HYDROSTATIC TEST CONDITION IS NOT REQUIRED. HOWEVER, IN ORDER TO PROVIDE A SATISFACTORY ENGINEERING DESIGN FOR THE PRESSURE SHELL THE FOLLOWING CRITERIA WAS USED:

- (a) THE MAXIMUM GENERAL MEMBRANE STRESS PERPENDICULAR TO A WELD LINE WAS LIMITED TO THE LESSER OF:

$$P_m * \leq 0.8 \text{ WELD YIELD STRESS}$$

OR

$$P_m * \leq 0.5 \text{ WELD ULTIMATE STRESS}$$

(b) THE GENERAL PRINCIPAL MEMBRANE STRESS IN THE
PLATE (NOT AT A WELD) WAS LIMITED TO THE LESS
OF:

$$P_m * \leq 0.8 \text{ PLATE YIELD STRESS}$$

$$P_m * \leq 0.5 \text{ PLATE ULTIMATE STRESS}$$

(*) THE STRESSES SATISFYING THIS CRITERIA ARE
BASED ON MAXIMUM MEMBRANE STRESSES
RATHER THAN INTENSITY CRITERIA.

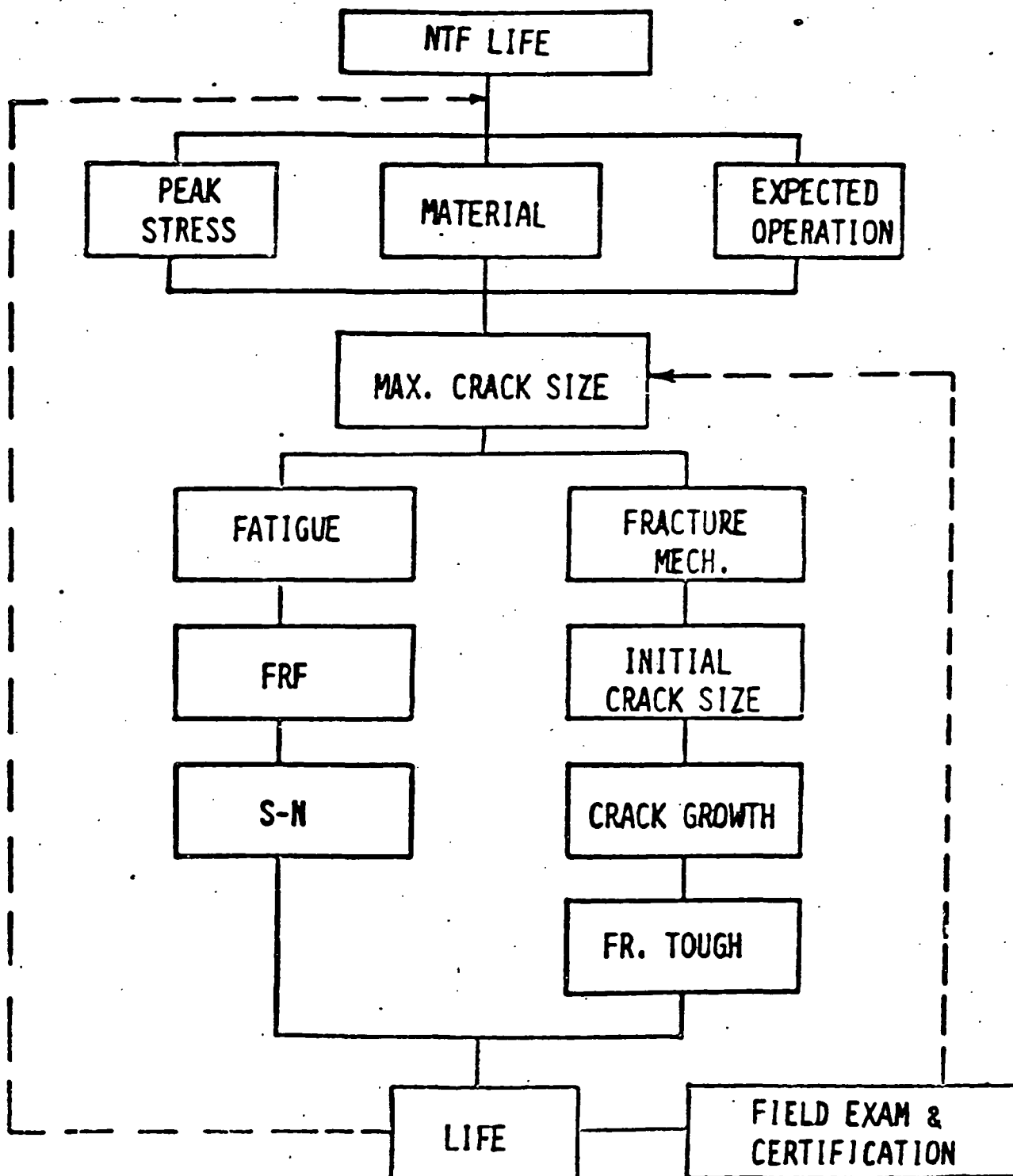
NTF 9% Ni
FATIGUE ANALYSIS

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APPROACH



Taylor, J.T.; Lewis, P.E.; and Ramsey, J.W., Jr.: A Procedure for Verifying the Structural Integrity of an Existing Pressurized Wind Tunnel. ASME National Pressure Vessel Conference, June 1974; and ASME JEMT, October 1974.

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BASIS FOR LIFE CYCLE ~~FAT.~~ ESTIMATE

—SHEAR WAVE ULTRASONIC TESTING

- 0 BASIS FOR INSPECTION FREQUENCY FOR NTF 50 YEAR LIFE REQUIREMENT
 - 1. ASSUME .03" MAX. INITIAL FLAW SIZE (APPLY FATIGUE REDUCTION FACTOR)
 - 2. APPLY OTHER APPROPRIATE ASME CODE FATIGUE REDUCTION FACTORS
 - 3. USE NTF PROJECTED LIFE CYCLE HISTORY (PRESSURE AND TEMPERATURES)
 - 4. USE STRESSES FROM RESULTS OF NTF SHELL DESIGN
 - 5. DETERMINE FATIGUE LIFE FROM ASME CODE S-N CURVES
- 0 NO SECONDARY INSPECTIONS DICTATED BY UT RESULTS OR AFTER REPAIR
- 0 ROUTINE INSPECTIONS (I.E. VISUAL AND MONITORING OF SELECTED AREAS) ASSUMED TO BE INDEPENDENT OF MATERIAL SELECTION
- 0 ASSUME VARIATIONS FROM FULL UT TECHNIQUE WILL AVERAGE OUT
- 0 NO REPAIRS INCLUDED
- 0 NO CRACKS → INFINITE LIFE EVERYWHERE

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1. ASME Boiler and Pressure Vessel Code. 1974 Edition.
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10. Vibration Committee Memo by Dr. J. W. Ramsey, Jr., updated 1/18/76

ASME CODE SECTION VIII

DIVISION 1 PROVIDES
REQUIREMENTS FOR:

- DESIGN
- FABRICATION
- INSPECTION
- CERTIFICATION
- HYDRO 1.5 X DESIGN PRESSURE
(36 KSI)
- PNEUMATIC 1.25 X DESIGN PRESSURE
(30 KSI)

DIVISION 2 PROVIDES FOR
IMPROVED QUALITY BY:

- MORE RESTRICTION ON CHOICE OF MATERIALS
- MORE PRECISE DESIGN PROCEDURES
- PROHIBITS SOME COMMON DESIGN DETAILS
- FABRICATION PROCEDURES ARE SPECIFICALLY DELINEATED
- MORE COMPLETE TESTING AND INSPECTION
- HYDRO 1.25 X DESIGN PRESSURE (40 KSI)
- PNEUMATIC 1.15 X DESIGN PRESSURE (36 KSI)
- PROVIDES FOR FATIGUE LIFE DUE TO CYCLIC
PRESSURE/TEMPERATURES

NTF NOW APPROACHES THIS WITH DIV. I ALLOWABLES

DESIGN (STRESS) CRITERIA

I. SECTION VIII - DIVISION I

PRESSURE: -15 TO 119 PSIG

TEMPERATURE: -320 TO 150°F

II. MATERIALS

9% NI STEEL

PLATE

SA-553-I

FORGINGS

SA-552

WELD CONSUMABLES

INCO-WELD A,B

INCONEL 82

III. MATERIAL PROPERTIES

(2" PLATE)

YIELD STRENGTH - PLATE OR FORGING

85 ksi

WELD METAL (MIN.)

52.5 ksi

TENSILE STRENGTH - PLATE OR FORGING

100 ksi

WELD METAL (MIN.)

95 ksi

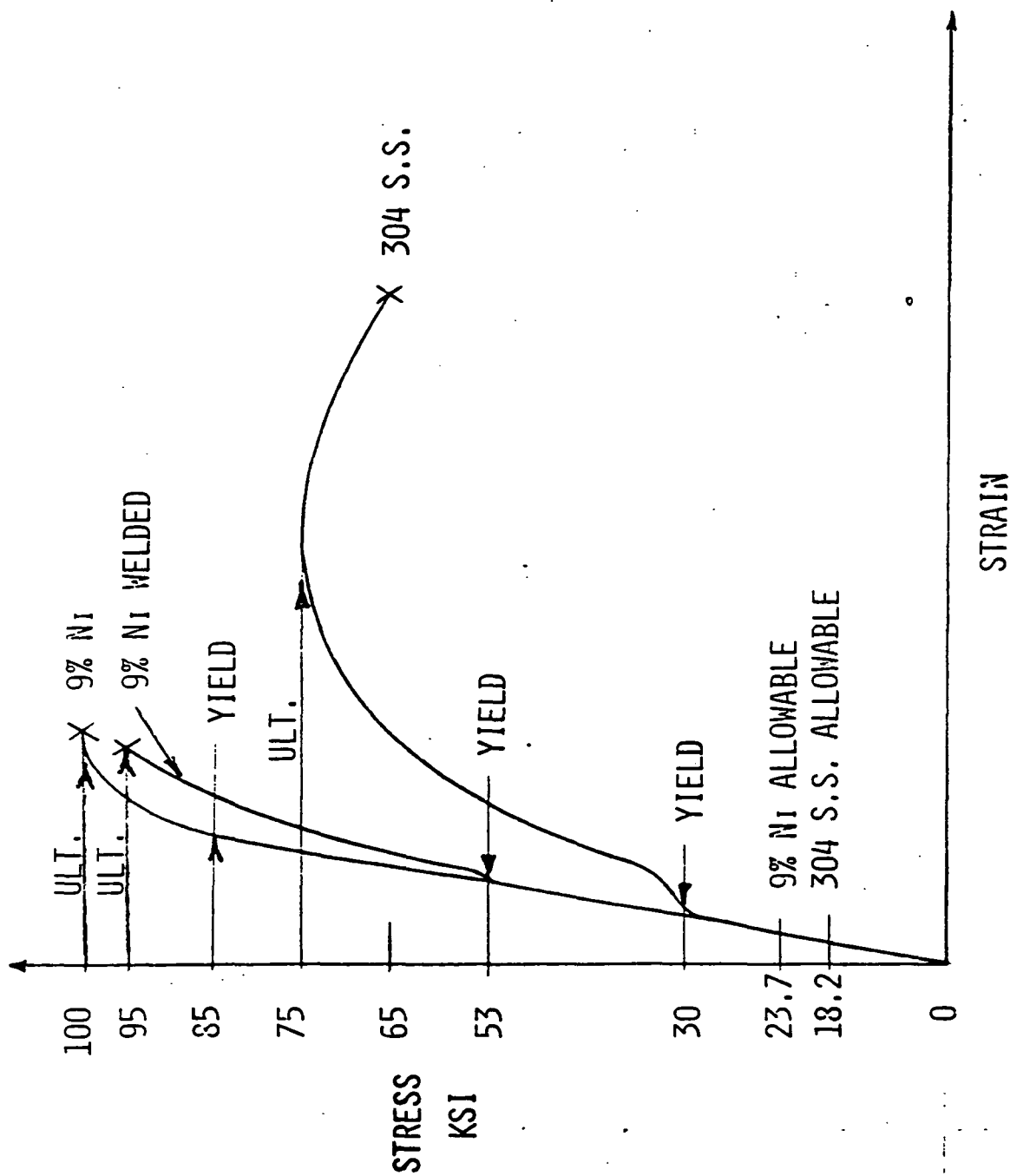
IV. ALLOWABLE STRESSES (150°F)

SECTION VIII DIV. I

23.7 ksi

SECTION VIII DIV. II

31.7 ksi



STRESS-STRAIN RELATIONSHIPS

FOR

NTF SHELL MATERIALS

- 7 -

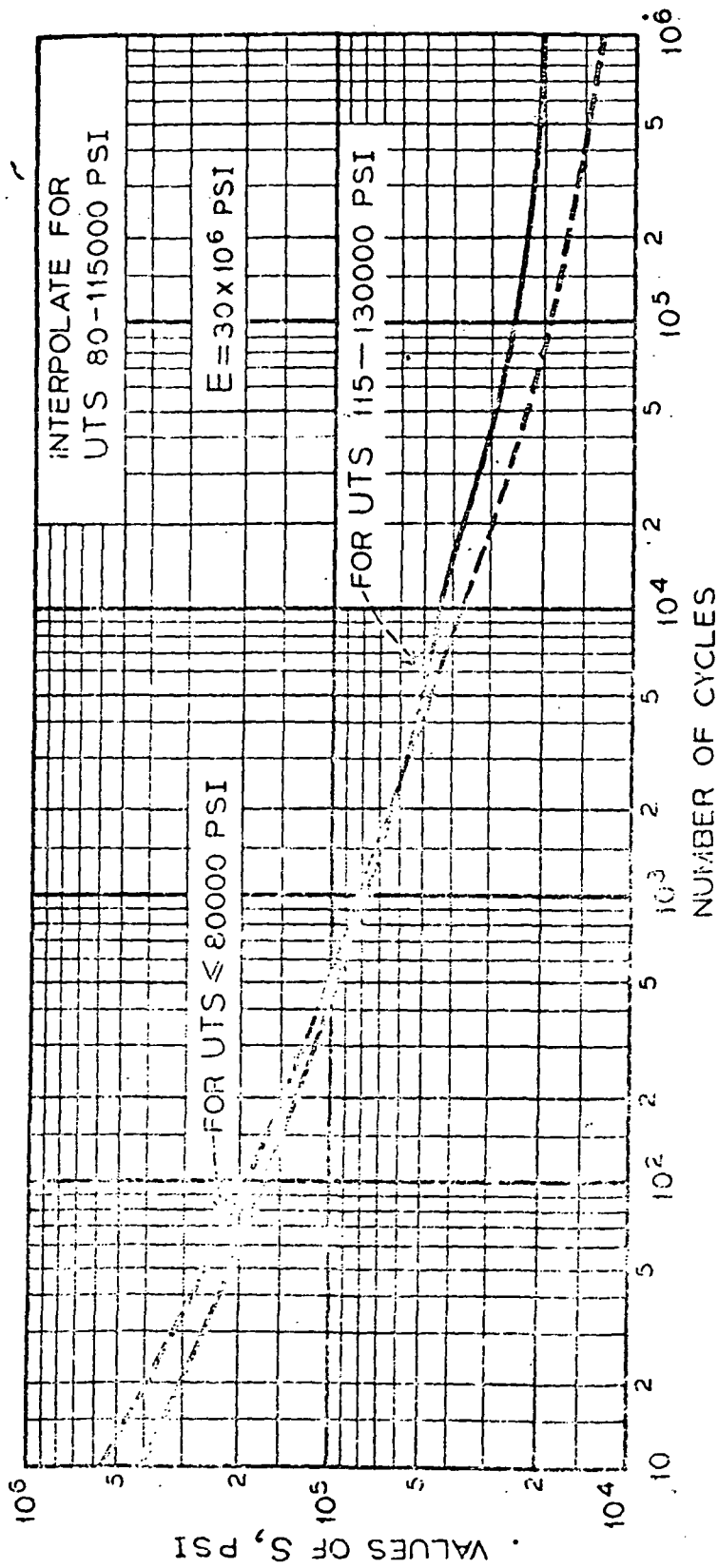


FIG. 5-110.1 DESIGN FATIGUE CURVES FOR CARBON, LOW-ALLOY, SERIES 4XX, HIGH-ALLOY STEELS AND HIGH TENSILE STEELS FOR TEMPERATURES NOT EXCEEDING 700 F

WFF CRUISING DATA SHEET

| CASE | PROGRAM | POLARS PER PROGRAM | MIX FACTOR | PROGRAMS PER YEAR | POLARS PER YEAR |
|------|------------------|--------------------|------------|-------------------|-----------------|
| I-A | CRUISE A/C | 189 | 30 | 15 | 2400 |
| II | MANEUVERING A/C | 203 | 30 | 12 | 2400 |
| III | MI, H, Q EFFECTS | 109 | 40 | 30 | <u>3200</u> |
| | | | TOTAL | | 8000 |

FIGURE 1

NTF OPERATIONAL PROFILE

WEEKS

0 4 8 12 16 20 24 28 32 36 40 44 48 52









-  - RUN, CASES I-A, II OR III
-  - RUN, AMBIENT
-  - REPAIR
-  - MAINTENANCE
-  - ANNUAL MAINTENANCE
-  - INSPECTION



FIGURE 2

ASSUMPTIONS

- ENTIRE TUNNEL BROUGHT TO ATMOSPHERE ON FRIDAY FOR WEEKLY INSPECTION - REMAINS AT ATMOSPHERE (1~70°F) OVER WEEKEND
- THREE SHIFTS DURING WEEK AS REQUIRED - NONE ON WEEKEND
- 12 HOURS BETWEEN PROGRAMS FOR MODEL CHANGE - TEST SECTION OPEN FOR CHANGES.
- PERIODIC REPAIR, MAINTENANCE AND INSPECTION DURATION OF ONE WEEK EACH.
- ONE YEARLY 4-WEEK PERIOD FOR MAINTENANCE, THOROUGH INSPECTION.

FIGURE 3

NTF WEEKLY OPERATIONAL SCHEDULE

 RUN
 MODEL CHANGES
 12 HOURS EACH

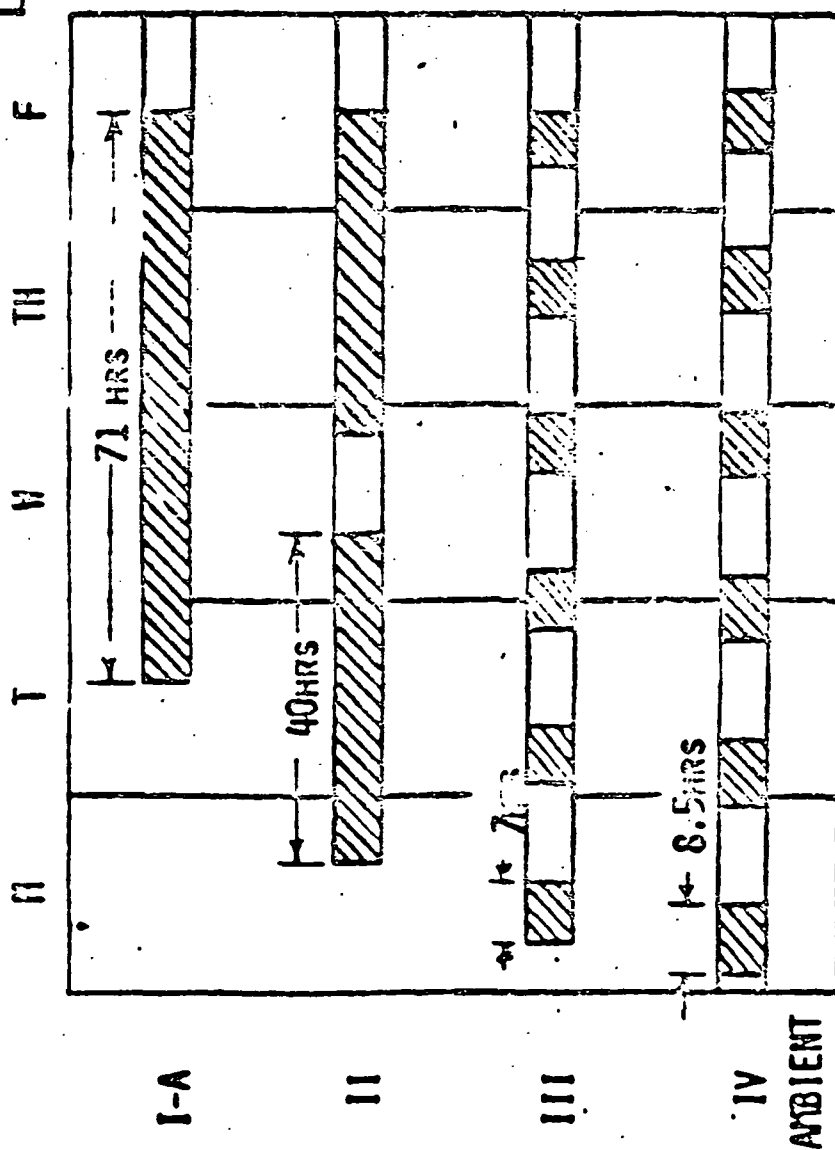


FIGURE 4

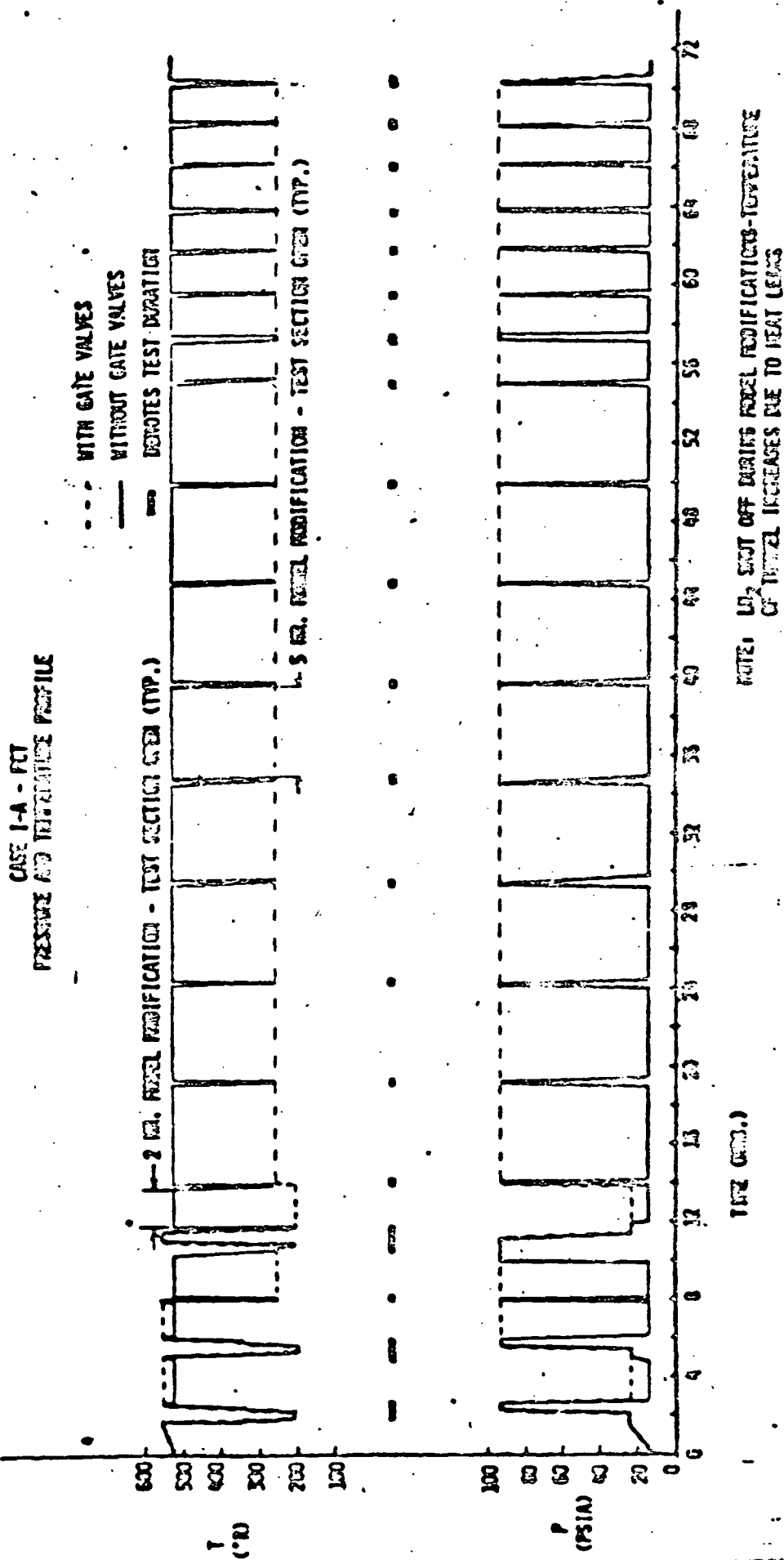
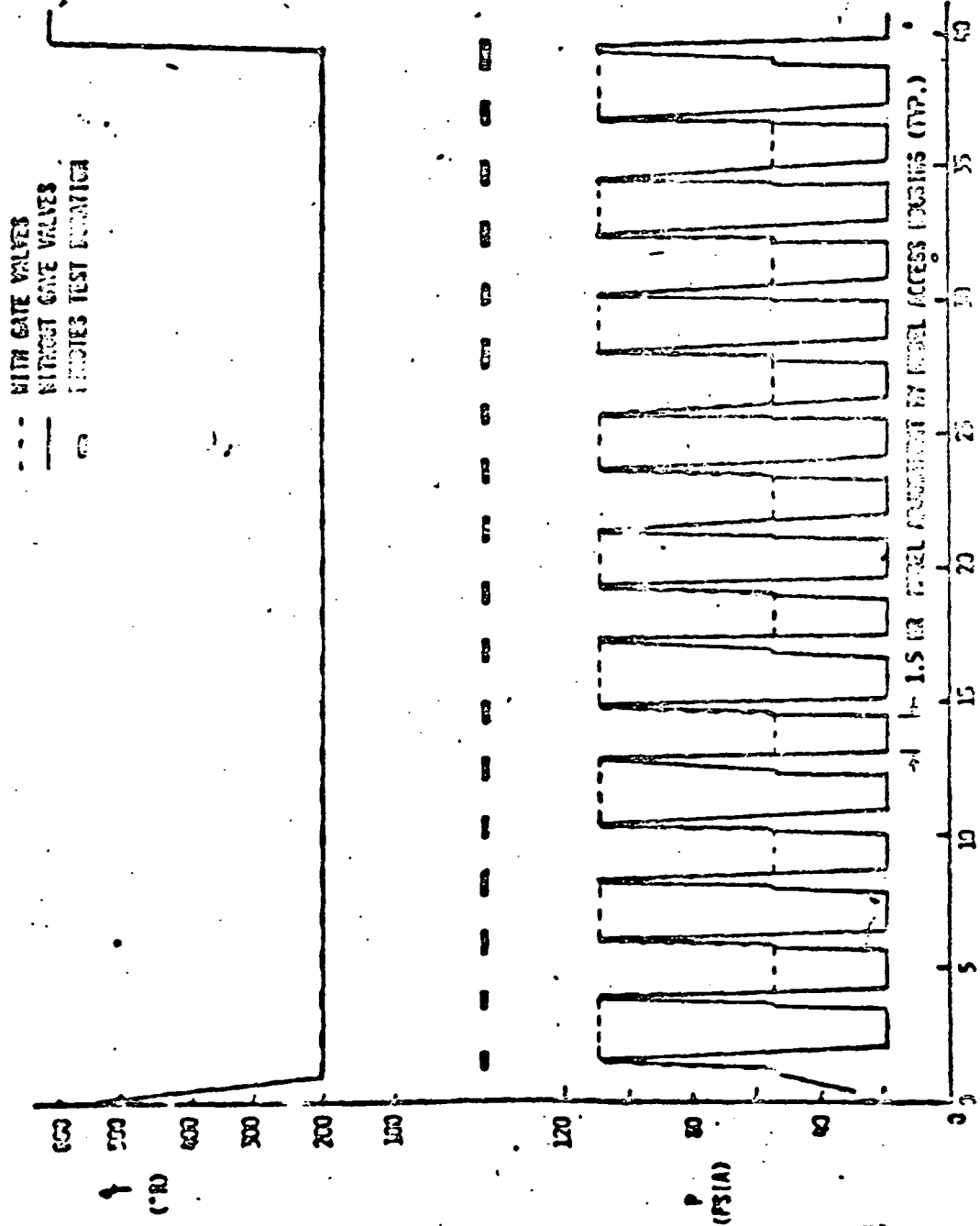


FIGURE 5

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CASE II - RATED AIRCRAFT PRESSURE AND TEMPERATURE PROFILE



NOTE: 1.5 HR. AFTER PRODUCTION BY MODEL ACCESS PORTS (MP.)
OF MODEL INCLUDES ONE TO NEAR LIPS

FIGURE 6

CASE III - BASIC RESEARCH PRESSURE PROFILE

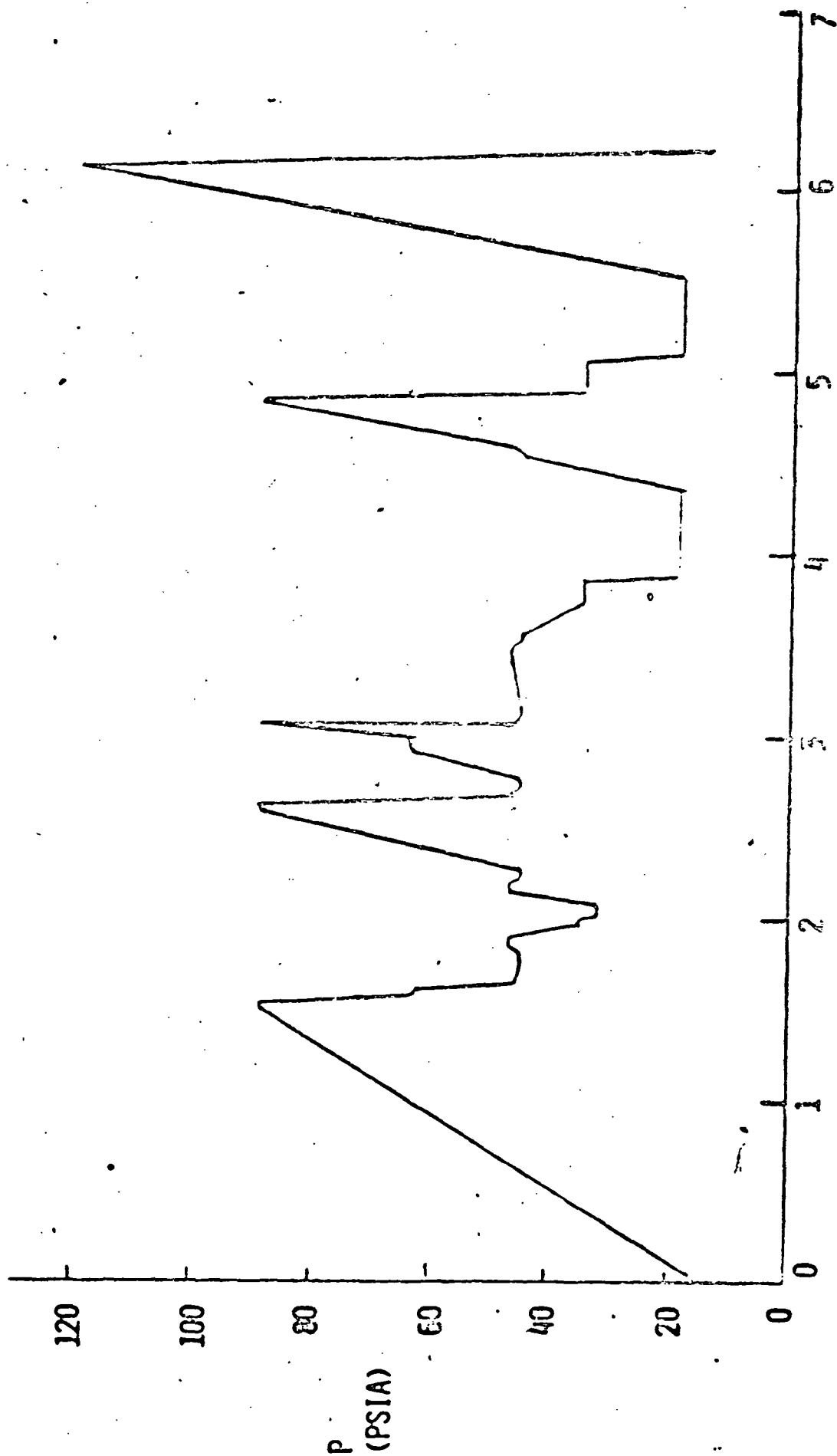


FIGURE 7

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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CASE III - BASIC RESEARCH
TEMPERATURE PROFILE

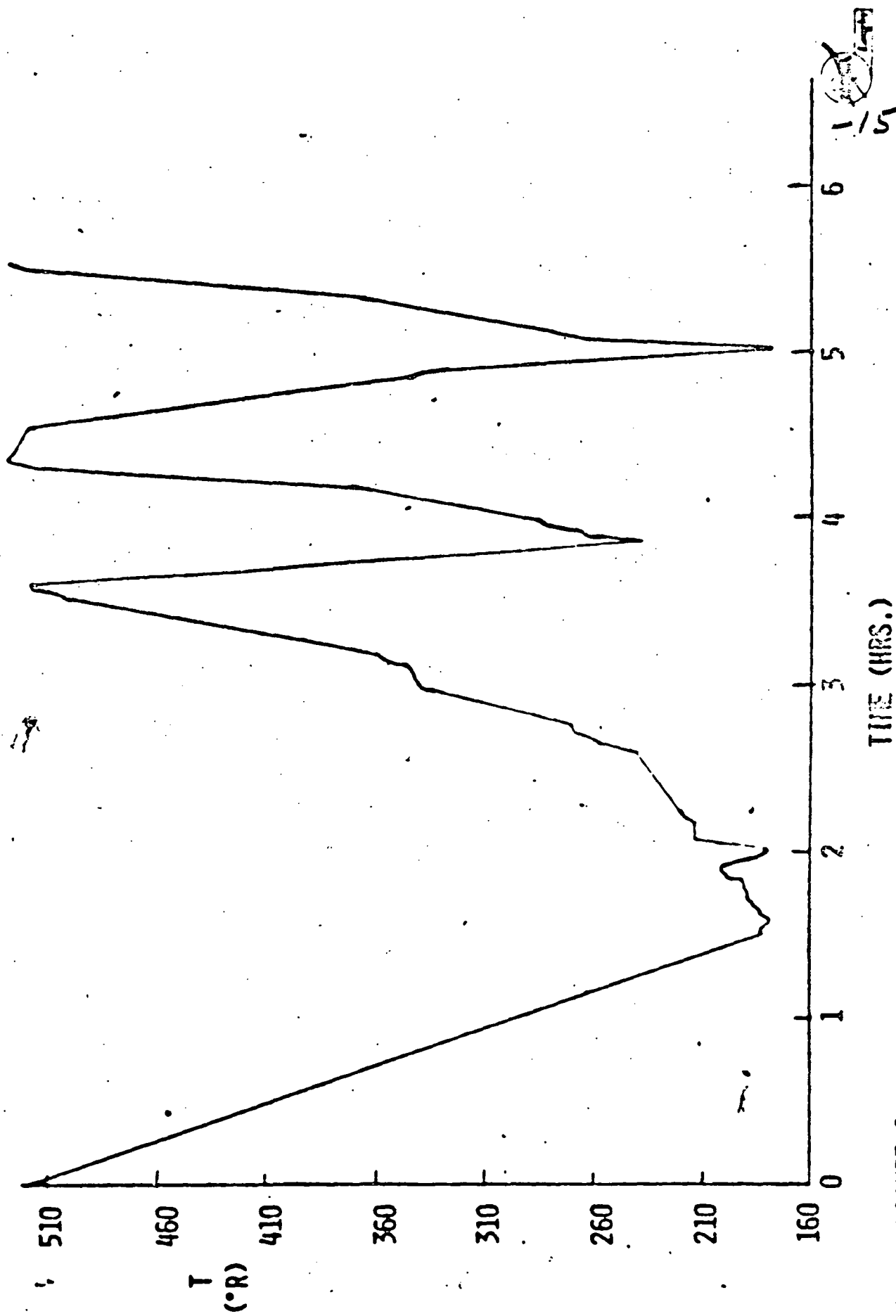


FIGURE 8

CASE IV - AMBIENT MODE

PRESSURE AND TEMPERATURE PROFILES

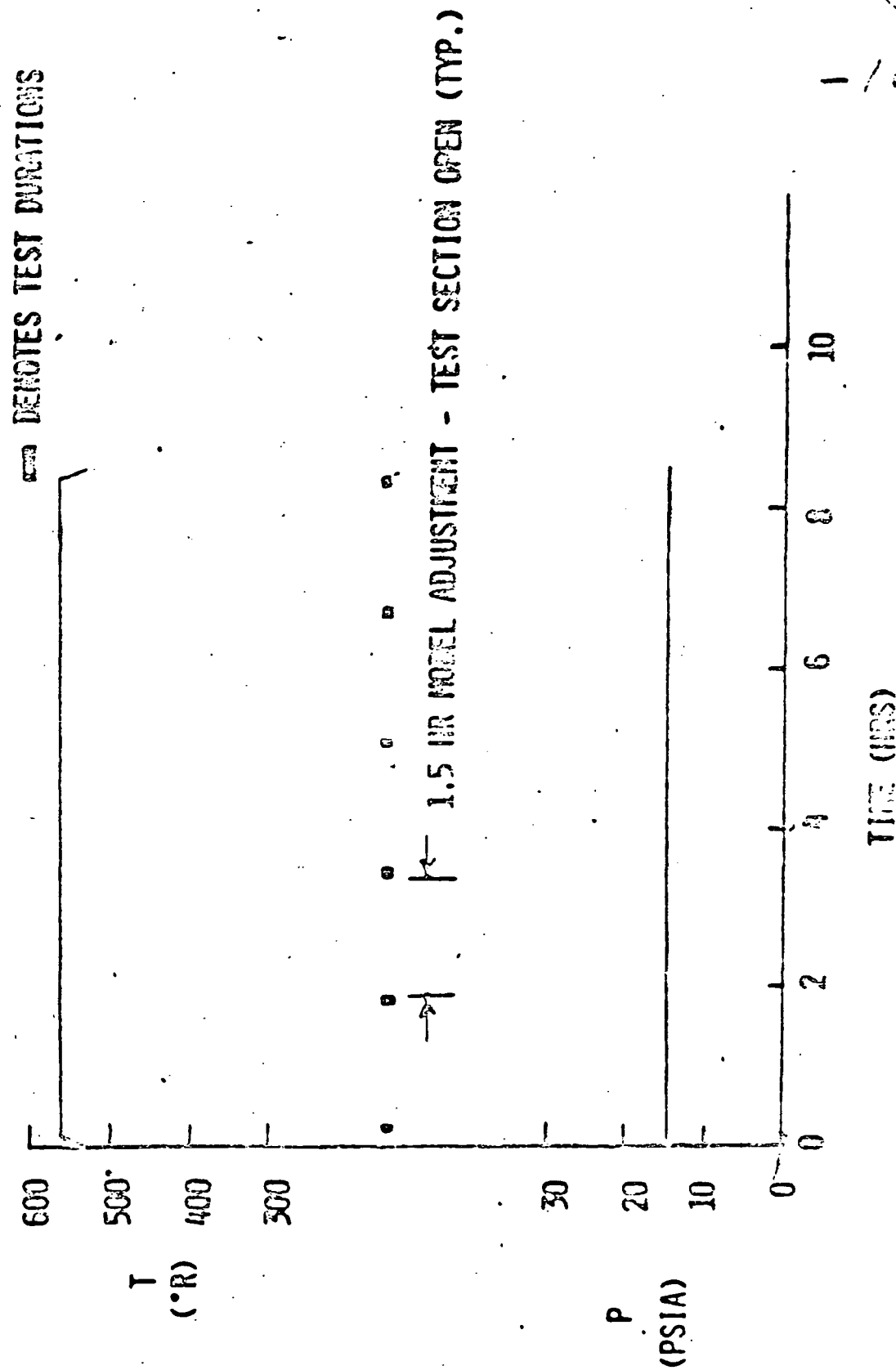


FIGURE 9

OPERATIONAL PROCEDURES
FOR
MINIMIZING MOISTURE IN THE WTF

INDEX

CASE A - CONSTRUCTION PHASE

CASE B - INITIAL STARTUP AND COOLDOWN

CASE C - CRYOGENIC CONDITION ~~-----~~ AMBIENT CONDITION FOR
ENTIRE TUNNEL ACCESS ~~-----~~ CRYOGENIC CONDITION

1. Weekend, annual, and as required inspections.
2. Repair and maintenance as required.
3. Ambient test following a cryogenic test.
4. Cryogenic tests.

CASE D - CRYOGENIC CONDITION ~~-----~~ AMBIENT CONDITION FOR
TEST SECTION AND PLENUM ACCESS ONLY ~~-----~~ CRYOGENIC
CONDITION

1. Model modifications/changes during research test programs.
2. Inspection, repair, and maintenance of test section, plenum, and model support apparatus as required.

CASE E - CRYOGENIC CONDITION ~~-----~~ MODEL ACCESS THROUGH
MODEL ACCESS HOUSING ~~-----~~ CRYOGENIC CONDITION

1. Model adjustments during research test program.
2. Model inspection, repair, and maintenance as required.

CASE F - AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS ~~-----~~
AMBIENT TEST ~~-----~~ AMBIENT CONDITION FOR ENTIRE
TUNNEL ACCESS

1. Ambient tests.
2. Model change/modification/adjustment during research test programs.
3. Inspection, repair, and maintenance as required.

NOTE: (TBD) indicates that a number is to be determined.

NOTE: Many of these procedures imply manual operations but in reality will be automatic control operations.

DESCRIPTION OF PROCEDURES

CASE A - CONSTRUCTION PHASE

During the construction and installation phases it is highly improbable that the tunnel shell interior and the insulation system can be completely protected from humid environments. It is recommended that once the shell is complete and installation of the insulation commences, all tunnel shell openings to the outside environment be closed and work occur through only those accesses exposed to the environment inside the building (such as the test section) which is conditioned by air conditioning and heating. It is recommended that relative humidity of this conditioned environment not exceed about 50 percent. This will prevent the insulation, upon being installed, from experiencing the very high relative humidities often occurring in the Tidewater area.

CASE B - INITIAL STARTUP AND COOLDOWN

1. Close and secure all tunnel accesses (including exhaust valve).
2. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.
3. Close vacuum system valve and backfill tunnel to about one atmosphere with dry heated air.
4. Repeat steps 2 and 3 until tunnel dewpoint is down to about 435°R. During this time maintain tunnel stream temperature above dewpoint temperature.
5. Open vacuum system valve and evacuate tunnel to about 8.3 psia pressure.
6. Close vacuum system valve.
7. Start fan and operate at minimum speed.
8. Open LN₂ valve and inject LN₂ into tunnel at low mass flow rate.
9. When pressure increases to about one atmosphere, open exhaust valve to maintain constant pressure in order to purge system.
10. Never allow stream temperature to exceed 635°R.
11. Purge system by maintaining constant pressure for at least ____ (TBD) hours with a stream dewpoint temperature of below 420°R.
12. Maintain stream temperature above dewpoint of stream until dewpoint temperature decreases below 380°R and stream oxygen level less than ____ (TBD) percent by volume.
13. Attain test conditions by controlling LN₂ flow rate, fan speed and pressure.

CASE C - CRYOGENIC CONDITION ~~----->~~ AMBIENT CONDITION FOR
ENTIRE TUNNEL ACCESS ~~----->~~ CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN₂ inlet valve.
2. Operate fan such that stream is heated and maintained at about ____ (TBD) °R for at least ____ (TBD) hours to warm tunnel interior. Maintain tunnel pressure at about one atmosphere.
3. If at end of a week, shut off fan and allow tunnel to warm up over weekend without opening. Assure that exhaust valve is closed.
4. If not at end of week, continue heating tunnel as in step 2 until liner and insulation considered sufficiently warm for opening tunnel.
5. Shut off fan and close exhaust valve.
6. Open vacuum system valve and evacuate tunnel to 8.3 ~~(TBD)~~ psia with vacuum system.
7. Close vacuum system valve and repressurize tunnel to about one atmosphere with dry, heated air.
8. Repeat steps 6 and 7 until oxygen level in tunnel is at least 20 percent by volume.
9. Open doors to tunnel and perform inspection, repair and maintenance as required. During this time maintain oxygen level at 20 percent or above by volume and air temperature above 500 °R by maintaining a positive pressure in the tunnel with dry, heated air.
10. During any time the fan is not turning and the tunnel contains dry, heated air, maintain a positive pressure in the tunnel with the dry air.

II. AMBIENT TO CRYO

1. Close and secure all tunnel accesses.
2. Close dry air inlet valve.
3. Open valve to vacuum system and evacuate tunnel to about 2.3 psia. Close vacuum system valve.
4. Start fan and operate at minimum speed.
5. Open LN₂ inlet valve and inlet LN₂ at low mass flow rate.
6. Open exhaust valve to maintain pressure at about 15 psia.
7. Maintain stream temperature above dewpoint of stream until dewpoint of stream decreases below 380°R and oxygen level decreases below ____ (TBD) percent by volume.
8. Never allow stream temperature to exceed 605°R.
9. Attain test conditions by controlling LN₂ mass flow rate, fan speed, and pressure.

CASE D - CRYOGENIC CONDITION ~~—————~~ AMBIENT CONDITION FOR
TEST SECTION AND PLENUM ACCESS ONLY ~~—————~~
CRYOGENIC CONDITION

I. CRYO TO AMBIENT

1. Close LN_2 inlet valve.
2. Close exhaust valve.
3. Shut off fan.
4. Close and secure gate valves.
5. Relieve plenum and test section of pressure to one atmosphere through plenum pressure control valve.
6. Purge plenum and test section with ____ (TBD) lbs per second mass flow of dry, heated air until oxygen content level reaches at least 20 percent by volume and until metal surfaces to be contacted warm sufficiently, depending on work to be performed.
7. Adjust dry air inlet mass flow rate as required in order to maintain a ____ (TBD) psia positive pressure, an air temperature of above 500°R , and an oxygen level of at least 20 percent by volume while working in the test section and plenum volume.
8. Perform work as required.

II. AMBIENT TO CRYO

1. Close and secure test section and plenum doors.
2. Close dry air exit and inlet valves.
3. Open gate valve bypass valve and pressurize plenum and test section with cold GN_2 from tunnel.
4. Open gate valves.
5. Start fan and slowly increase speed.
6. Attain test conditions by controlling LN_2 flow rate, fan speed, and pressure.

CASE E - CRYOGENIC CONDITION ~~MODEL ACCESS VIA MODEL~~
ACCESS HOUSING ~~CRYOGENIC CONDITION~~

I. CRYO TO MODEL ACCESS HOUSING INSERTION

1. Close LN₂ inlet valve.
2. Close exhaust valve.
3. Shut off fan.
4. Close and secure gate valves.
5. Relieve plenum and test section pressure to one atmosphere through plenum pressure control valve.
6. Condition model access housing tubes with warm, dry air.
7. Open plenum and test section doors.
8. Insert and seal model access housing tubes.
9. Circulate warm, dry air through housing such that oxygen level is maintained to at least 20 percent by volume and temperature maintained above 500° R.
10. Perform model adjustment/inspection as required.

II. MODEL ADJUSTMENT/INSPECTION TO CRYO

1. Close doors to housing such that dry air environment in housing is maintained once personnel are evacuated.
2. Retract housing tubes.
3. Close and secure test section and plenum doors.
4. Open gate valve bypass valve and pressurize plenum and test section with cold GN₂ from tunnel.
5. Open gate valves.
6. Start fan and slowly increase speed.
7. Attain test conditions by controlling LN₂ flow rate, fan speed, and pressure.

CASE F - AMBIENT CONDITION FOR ENTIRE TUNNEL ACCESS ~~—————~~
AMBIENT TEST ~~—————~~ AMBIENT CONDITION FOR ENTIRE
TUNNEL ACCESS

I. AMBIENT CONDITION TO AMBIENT TEST

1. Close and secure all tunnel accesses.
2. Close dry air inlet valve.
3. Start fan.
4. Attain test conditions by controlling fan speed, cooling coil water flow, and pressure.
5. Perform test.

II. AMBIENT TEST TO AMBIENT CONDITION

1. Shut off fan.
2. Open dry air inlet valve to maintain positive pressure of ____ (TBD) psia in tunnel.
3. Before entering tunnel, assure that oxygen content is at least 20 percent by volume and temperature above 500° R.

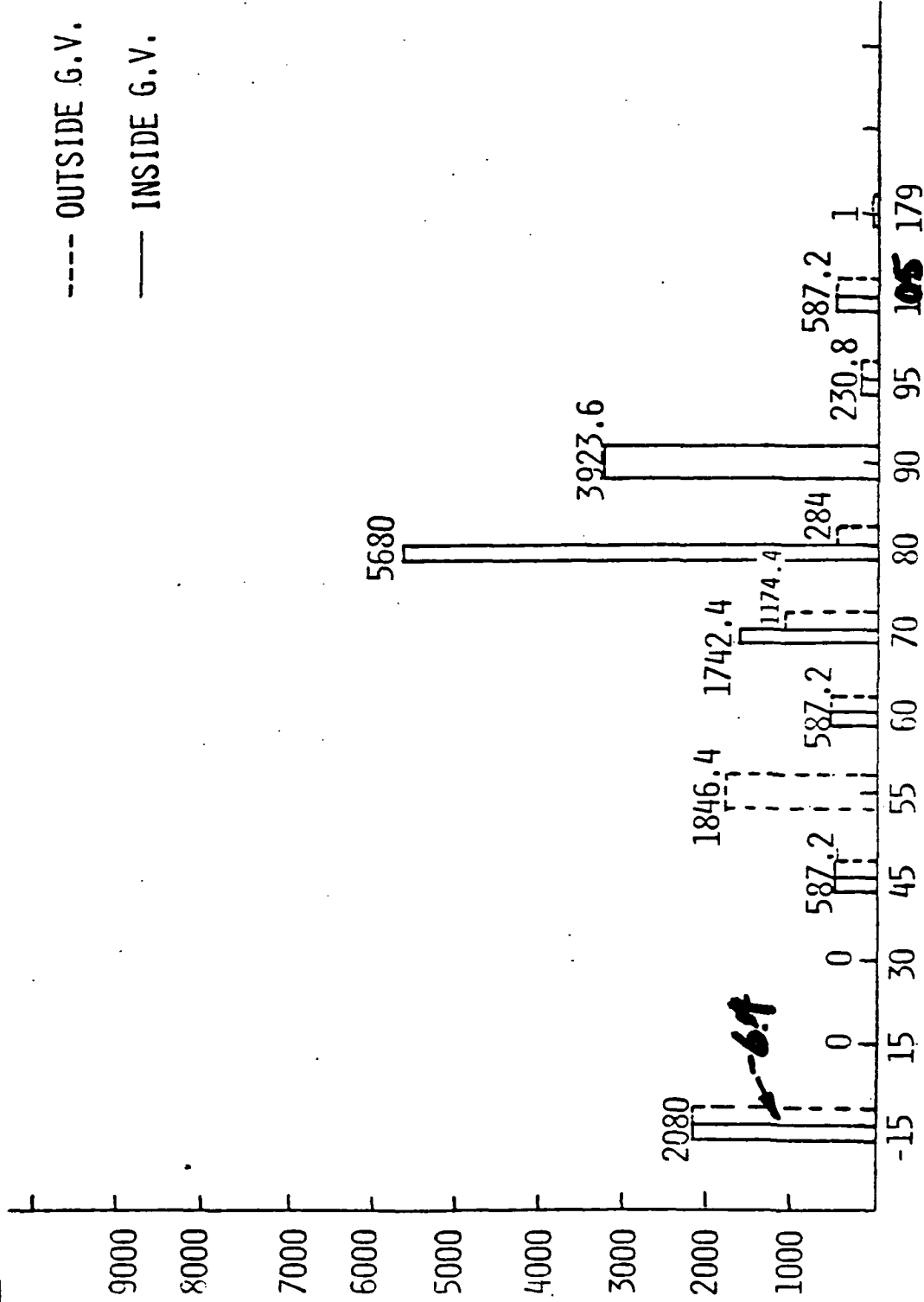
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20 YEAR PRESSURE CYCLIC PROJECTION OF NTF

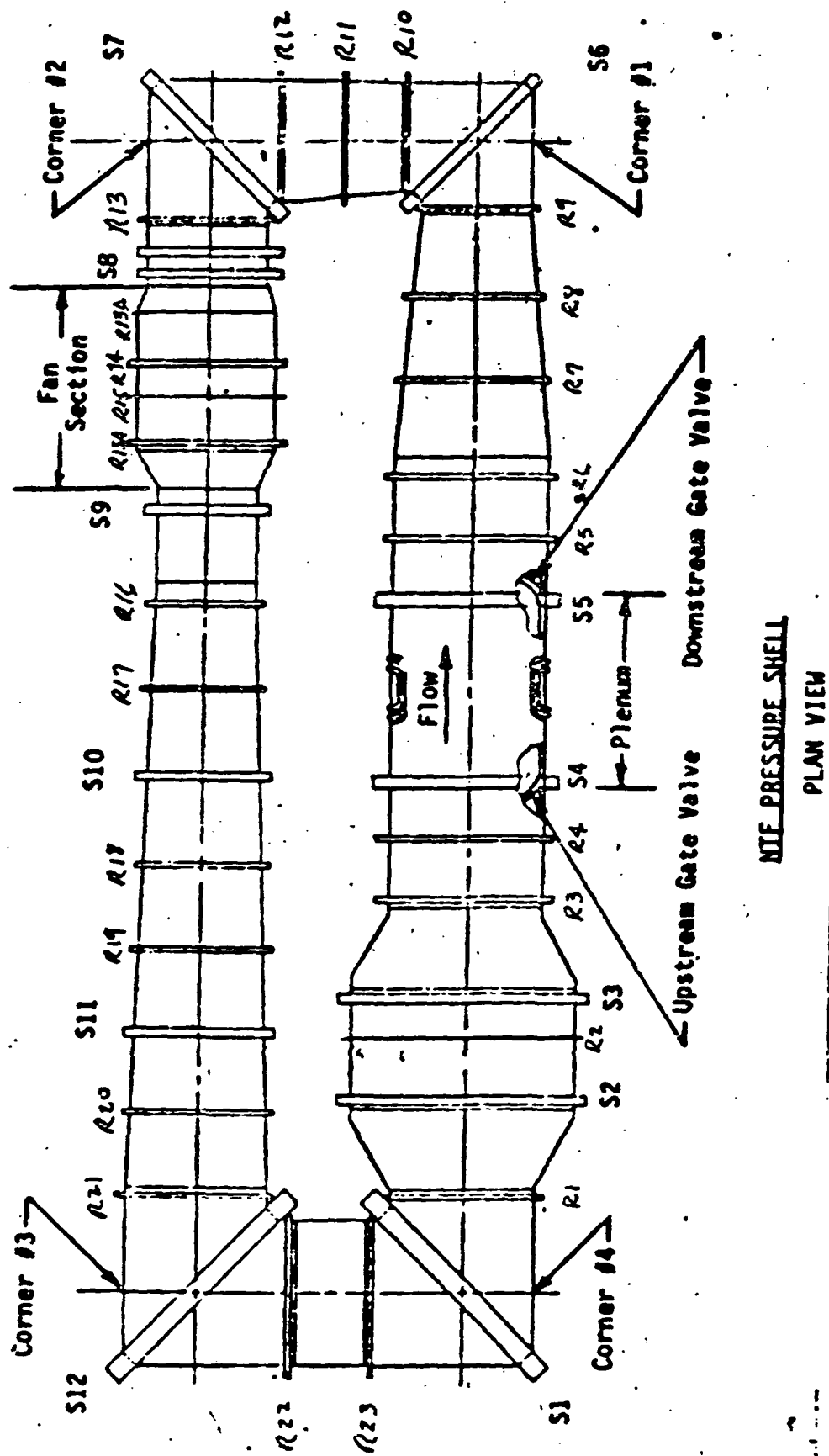
CYCLES

----- OUTSIDE G.V.

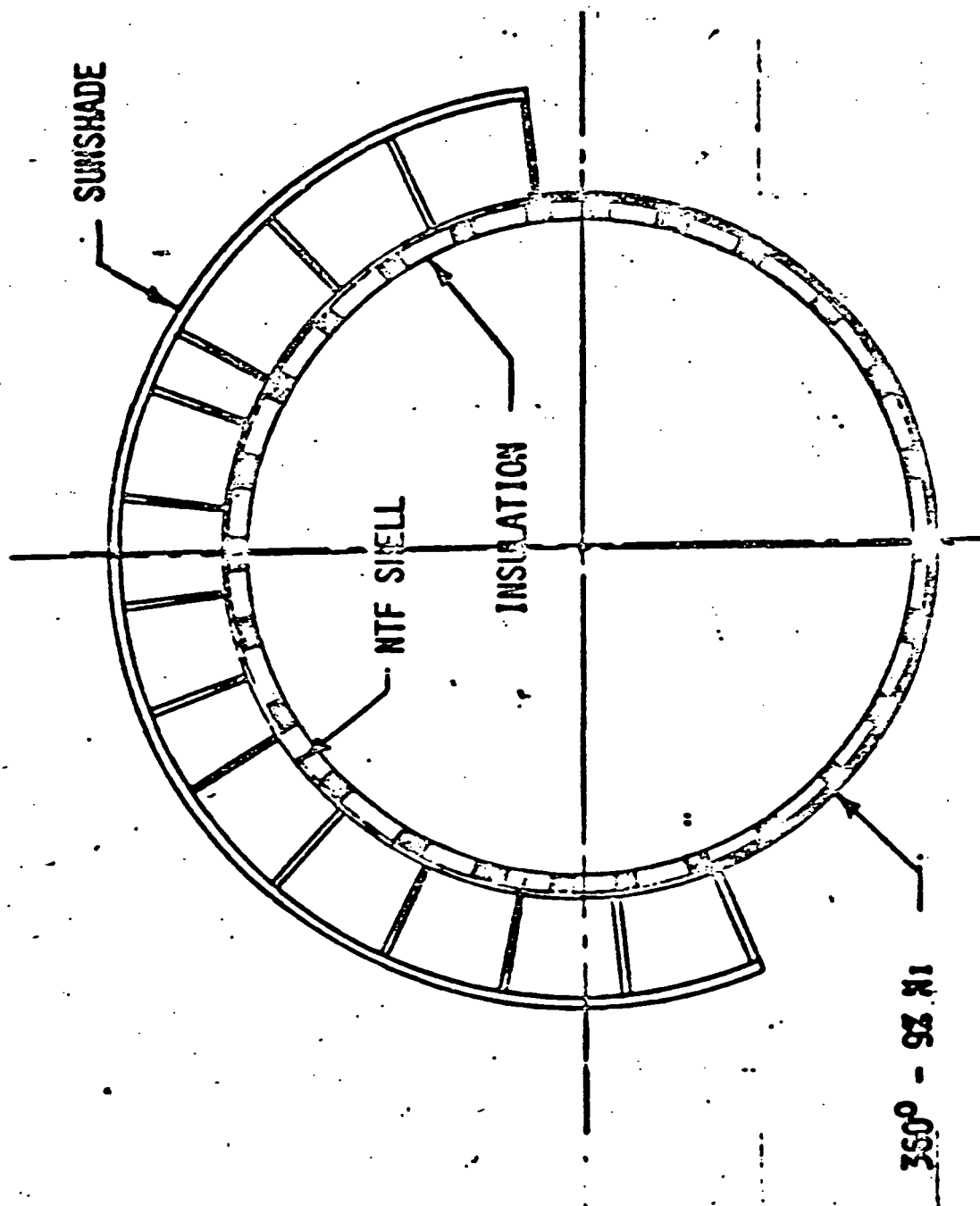
—— INSIDE G.V.



Δ PRESSURE, PSI



NASA LANGLEY RESEARCH CENTER



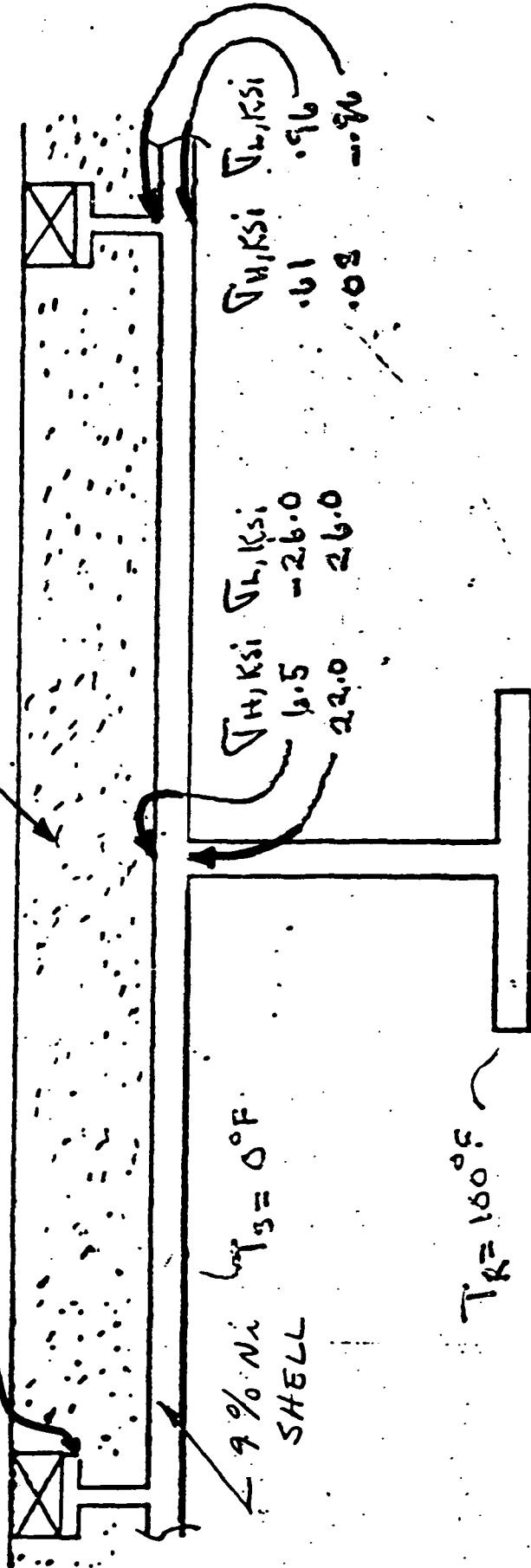
EXTERIOR SURFACE PAINTING FOR NTF-SHELL

THERMAL PROFILE

$T_f = -280^{\circ}\text{F}$

$T_s = 10^{\circ}\text{F}$

6" TEMP-MAT INSULATION



| σ_H, Ksi | σ_L, Ksi | σ_H, Ksi | σ_L, Ksi |
|------------------------|------------------------|------------------------|------------------------|
| 1.5 | -26.0 | .61 | .96 |
| 22.0 | 26.0 | .08 | -.96 |

NOTE: The new Baseline Insulation is a closed cell material - "Rohacell", which results in reducing the above stresses by a factor of 10.0.

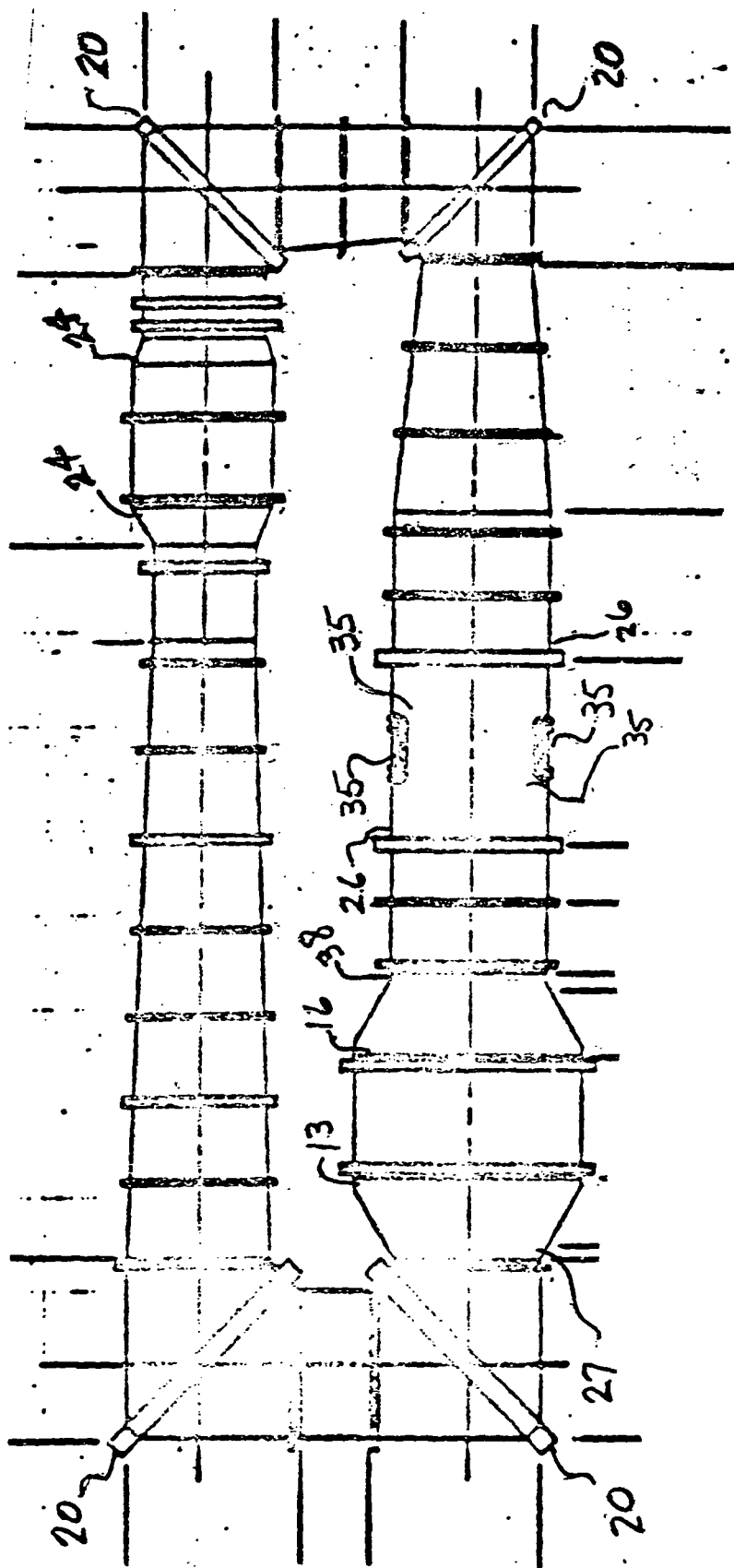
$T_a = 100^{\circ}\text{F}$

INTERNAL INSULATION

HTF PRESSURE SHELL

< 50 YEARS (AS NOTED)
> 50 YEARS OTHER

90 NI



NTF QC PROGRAM FOR CONSTRUCTION — ASME CODE
EQUIVALENT SECT. 8 DIV. 2 & SECT. 3

- ① NEAR 100% X-RAY PRESSURE WELDS
- ① DYE PENETRANT WELD PASSES
- ① 100% ULTRASONIC EXAMINATION OF PLATES
- ① WELDING PER ASME SECTION 9
- ① NONDESTRUCTIVE EXAMINATION BY ASME SECT. 5 AND 11
- ① CLOSE NASA/LARC INSPECTION CONTROL
- ① ALL SIGNIFICANT DEFECTS REPAIRED